$$f(t) = Re^{-RT}$$

Because overloads cause the source to be choked down instead of continuing to fill (and possibly overflow) the buffer, the request may simply go away by the time a demand channel becomes available. This model is analogous to the "Erlang B"[1] telephone traffic model (lost-calls-cleared).

A strong argument can be made that the holding time distribution for this model is exponentially distributed, also a common assumption is telephone traffic theory. However, the lost-calls traffic model is actually independent of the individual holding time distribution and depends only on the average holding time "h". The offered traffic (in Erlangs) is A = Rh.

For an N-server system, a request is denied if and only if exactly N source requests are currently active. Therefore, the PMD is determined from the conditional Poisson distribution and is known as the Erlang B formula:

$$PMD = \frac{\frac{A^N}{N!}}{\sum_{i=0}^{N} \frac{A^i}{i!}}$$

The above model is based on the infinite source Poisson model. This is reasonable under the given assumptions and actually results in conservative engineering. However, a more accurate analysis is based on the finite model conditional binomial distribution due to Engset[2] and Martin[3]:

$$PMD = \frac{\binom{M-1}{N} a^N}{\sum_{i=0}^{N} \binom{M-1}{i} a^i}$$

$$a = \frac{A}{M - A}$$

where "a" is the traffic offered by a free source and M is the number of sources. (For simplicity, we have ignored the difference between "offered" traffic and "carried" traffic which are essentially the same for small PMD.)

Another formula (used mostly in the U.S.A.) is from the lost-calls-held model of Molina:[4]

$$PMD = e^{-A} \sum_{i=N}^{\infty} \frac{A^i}{i!}$$

This may actual be the better model for the PMD because it assumes that the remaining portion of a request period is granted as soon as a demand channel becomes available. It still counts an initially denied request as degraded, although the intensity and noticeability of the degradation may be less. Use of this formula results in the most conservative engineering design of the three that have been presented.

In the case where each channel is known to have different requirements for access to the demand channels, it is possible to evaluate the PMD in a manner similar to Engset but using a generating function. If $a_i$ is the traffic from source "i" then the basic probabilities can be determined from:

$$P(z) = \sum_{i=0}^{M} c_i z^i = \prod_{j=1}^{M} \left(1 - a_j + a_j z^j\right)$$

and the PMD is given by:

$$PMD = \frac{c_N}{\sum_{i=0}^{N} c_i}$$

All of these models require that the basic parameters of the individual (or aggregate) sources are known. For a particular coder and type of programming, it should be relatively easy to determine these parameters empirically.

For other types of program sources, other statistical methods and criteria of goodness may be necessary, For example, a fixed bit-rate may be allocated for a class of services each of which consists of voice transmission augmented with still-frame video or object-oriented graphics. In this case, the voice transmission might require a fixed transmission capacity while the video is transmitted on a demand-request basis.

This is a considerably different problem from the (real-time) motion TV video considered in the preceding paragraphs. Motion degradation is not the issue here--"delayed" response is the real issue. All transmissions eventually get through. Therefore the criterion of goodness (or GOS) is the promptness of response to a demand service request. This is a Queueing Theory problem. If we first consider the Probability-of-Delay (POD) then, returning to the equivalent telephone traffic theory, the "Erlang C" delayed-call formula is applicable:

$$POD = \frac{\frac{A^N}{N!}\left(\frac{N}{N-A}\right)}{\sum_{i=0}^{N-1}\frac{A^i}{i!} + \frac{A^N}{N!}\left(\frac{N}{N-A}\right)}$$

The average waiting time (averaged over all service requests) is given by:

$$\bar{W} = \frac{POD}{N-A}$$

The probability that the delay exceeds time "t" is a negative exponential given by:

$$F(t) = PODe^{-(N-A)t}$$

The conditional probability of a <u>delayed</u> service request exceeding time "t" is given by:

$$\frac{F(t)}{F(0)} = e^{-(N-A)t}$$

For services requiring constant holding times (e.g., transmission of bit-mapped still frames), the analysis of Pollaczek[5] and Crommelin[6] is applicable. However, for most applications their results are essentially the same as for exponentially distributed holding times.

The tools presented here should be very useful in engineering homogeneous sub-classes of services for digital broadcast satellite transmission. However, a composite heterogeneous service, consisting of many different types of services, is more difficult to analyze in a closed-form mathematical approach.

The more general approach is to develop a Monte Carlo simulation model which would allow arbitrary numbers of each of several sub-classes of pre-defined services. This is relatively easy to do on today's Personal Computers. Initial service would begin with substantial margin since it takes time to build up the customer user base. Meanwhile, the detailed simulation model could be developed and actual statistics could be collected in order to refine the model and gain confidence to allow a smaller operating margin.

1 Erlang, A.K., "Solution of some problems in the theory of probabilities of significance in automatic telephone exchanges," *Post Off. Electr. Eng. J.*, 1918, 10, pp.189-197.

2 Engset, T., "Die Wahrscheinlichkeitsrechnung zur Bestimmung der Wahleranzahl in automatischen Fernsprechamtern," *Electrotech. Z.*, 1918, 31, pp. 304-305.

3 Martin, N.H., "A note on the theory of probability applied to telephone traffic problems," *Post Off. Electr. Eng. J.*, 1923, 16, pp. 237-241.

4 Molina, E.C., "The theory of probabilities applied to telephone trunking problems," *Bell Syst. Tech. J.*, 1922, 1, pp. 69-81.

5 Pollaczek, F., "Uber eine Aufgabe der Wahrscheinlichkeitstheorie," *Math Zeit.*, 1929-30, 32, pp.64-100 and 729-750.

6 Crommelin, C.D., "Delay Probability Formulae," *Post Off. Electr. Eng. J.*, 1934,26, pp.266-274.

# DIGITAL DBS EDUCATIONAL SERVICES:

# A PLAN FOR THE 1990s

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Prepared for: Advanced Communications Corporation

by: G. Gordon Apple, PhD

SUMMARY

A marriage of DBS (Direct Broadcast Satellite) and microcomputer technology will, for the first time in history, allow a complete spectrum of educational video and data broadcast services to be offered to the entire nation. Coverage will be universal, flexible, and economical. A brief description of the proposed services and system is presented along with plans for acheiving this goal.

## INTRODUCTION

DBS satellites and microcomputer technology -- What do they mean for the future of educational broadcast services? There are two answers. For the first time in history, we will have:

* Universal service coverage.
* Total flexibility of services.

No longer will a course not be available simply because of limited budgets or specialized subject matter. The flexibility of a digital DBS educational service will allow a complete spectrum of high-quality services to be offered to meet almost every need and budget.

To reach these goals, Advanced Communications Corporation (ACC) has proposed a Phase 1 program to refine objectives and design the system.

## EDUCATIONAL BROADCAST NEEDS IN THE 1990s

The need for educational broadcast services has never been greater. This need will continue to grow through the 1990s and beyond. Teachers, faced with limited budgets, large classes, and sometimes uninterested or overworked parents, need all the help they can get. Disparate salaries between teaching and industry have made math and science instructors a dying breed.

Technology and trade imbalances have resulted in a large demand for career retraining. Rapid advances in science, technology and medicine have made professional retraining and specialized news services and seminars essential for preventing obsolescence.

A changing world with "glasnost", continuing regional conflicts, open doors in China, and concern for the environment has made an enlightened public necessary for intelligent electoral choices and the assurance of world peace. The ravages of cancer and AIDS have made up-to-date in-depth information essential for both the public and for medical researchers and practitioners.

Although video cassettes can fulfill some of the needs, by far the most economical and timely means of providing many of these services is through broadcast television. Even so, many other such services are not available to much or all of the population due to transmission expense, limited air time, limited educational (or any) television coverage, or the specialized nature of the subject.

Technological changes such as HDTV (High Definition Television) also threaten to make obsolete the very television broadcasting system and receivers which have served us well, if not completely, in the past. A broadcast educational service implemented in the near future should be designed to be immune from technological obsolescence.

For these reasons, there is a pressing need for a flexible, economical, educational broadcast service with universal coverage.

## PROVIDING THE SERVICES

Two major technological developments have made it possible to provide all of the desired services within the near future:

> DBS (Direct Broadcast Satellite) television is becoming a reality with an experimental Japanese system in place, German satellites planned for fall '87 launch, a recently financed British system planned for fall '89 launch, and a recent DBS RFP (request for proposal) from the Australian Government.
>
> Low-cost digital computer technology, with inexpensive micro-computer chips, memories, and signal processors, is now available and will continue to become even more economical with time.

DBS systems use high power transmitters (100 w or more), high frequency (12 GHz), and small receiver antennas (e.g., 2'). Designs for satellites having 16 active transponders have been completed in the U.S. ACC is in the forefront of planning and technology for providing such DBS service in the U.S.

Although analog transmission may be used initially in these DBS systems (with a substantial amount of digital signal processing), ACC has proposed to the FCC that the DBS service in the U.S. be totally digital from the beginning.

For normal television service, each satellite transponder will carry a single television channel for half-CONUS coverage. However, such a single transponder could alternatively carry a multitude of educational services.

The provided services are presently envisioned to include four categories:

1. Full movie transmission.
2. Full motion, high quality for lectures.
3. Voice plus still-frames. (Rapid change capability. This is <u>not</u> slow scan. Animation is also possible.)
4. Data transmission (e.g., reading material, exams).

The relative cost differential between these services is substantial. For example, the relative transmission cost for categories 2 and 3 might be only 10 % and 1 %, respectively, of that of category 1.

By providing such a range of services, the system can be tailored to the needs and budget of each originating user. The system will have total flexibility. The service mix and even the service category definitions can be changed dynamically from one program period to another (e.g., 1/2 hr.). Regardless of the chosen video service, the end user will always receive a full resolution image. Changes in the service category (or ever redefined categories) will be transparent to the user since his receiver will automatically be reprogrammed through the satellite. Thus, even compatibility with future HDTV and 3-D will be assured and future obsolence will be avoided.

The proposed system is technologically feasible. The economic feasibility is a function of time, market size, and application. For many applications it is feasible now. By the time ACC's DBS satellites are operational it should be economically feasible for all.

The immediate goal of the Phase 1 program is a precise initial service definition and the development of the system design. This will pave the way for later detailed engineering design, a service trial, and eventual full scale implementation.

## OPPORTUNITIES TO BE EXPLORED

The desirability and feasibility of providing the described services are both evident. However, establishment of precise service and operational goals and the engineering design of this system requires further study and design effort. To accomplish these objectives, a Phase 1 study and design program is proposed which will provide answers and design architectures covering the following topics:

* Types of services
* Video compression and multiplexing
* Receiver video data decompression
* Receiver architecture
* Service access control
* Satellite Communication link
* Ground station systems architecture
* Service Origination Network
* Two-way service feasibility
* VCR simulation of services
* Plan for Phase 2

Each of these areas covers a multitude of questions and design issues which will be expanded upon in a later formal proposal. No major technological or operational obstacles are foreseen. The issues all involve precisely defining and refining the service objectives and the system design and planning for a detailed design phase (Phase 2).

## STRATEGY FOR SUCCESS

In order to make optimum use of time, funds, and personnel resources, a phased development is proposed with reevaluation of objectives, progress, and related developments (e.g., DBS satellite status) near the completion of each phase. Four phases are proposed:

PHASE 1 (System)
- System studies and architectural design.

PHASE 2 (Design)
- Detailed system, hardware and software design.
- Develop and test prototype system.

PHASE 3 (Production and trial)
- Manufacturing design and initial receiver production.
- Initial ground station and Service Origination Network.
- Service Trial.

4 (Deployment)

- Full volume production of receivers.
- Full ground station and Service Origination Network.
- Begin full service operation.

## OPPORTUNITY FOR ACTION

ACC is prepared to proceed with the Phase 1 system study and architectural design beginning in the fall of 1987. The breadth and depth of this effort will, of course, depend on the availability of appropriate funding.

ACC is prepared to meet with interested parties and provide vu-graph presentations illustrating the system concepts and outlining the proposed Phase 1 effort. Upon reaching a general consensus of objectives and approximate funding, ACC is also prepared to submit a formal proposal including the detailed Phase 1 objectives, the means of achieving the stated goals, qualifications of key personnel, management plan, expected cost, and schedule.

ACC has available some of the most qualified communications engineering, marketing and educational talent in the United States. Full-time employees will perform the majority of the agreed tasks. Uniquely qualified consultants will augment this effort. Depending on the agreed level-of-effort, subcontracting of portions of the work to specialized firms will also be considered.

The concept and potential of this program has stimulated considerable interest from those individuals and organizations with which it has been discussed. The recognition of the revolutionary implications of a flexible digital DBS educational service is readily apparent to those who would be involved.

The time for action is now, when we can have the most influence in directing the future of the U.S. DBS system to insure that these educational services will become a reality. The proposed Phase 1 program will accomplish this goal.

## CONCLUSION

Clearly, a new age in education is dawning. The marriage of low-cost microcomputer technology and universal coverage DBS satellites presents an unprecedented opportunity for educational broadcast services. For the first time in history, it is possible to economically provide a vast number of educational services to the entire population.

The flexibility of a digital DBS educational service will insure that almost all needs can be met. Quality math, science and other needed programming will be available to the entire nation. Even low-budget or highly specialized programming can still reach all who so desire.

APPENDIX OPPORTUNITIES TO BE EXPLORED (expanded)

* Types of services
  - Classes of services to be initially considered for system evaluation.
  - Relative broadcast transmission cost of selected services.

* Video compression and multiplexing
  - Compressor architecture(s).
  - Dynamic multiplexing of multiple diverse services.
  - Remote compression compatibility.

* Receiver video data decompression
  - Applicable compression algorithms with emphasis on decompression (receiver) techniques.
  - Common video processor architecture.
  - Method of downloading algorithms.

* Receiver architecture
  - Outdoor unit (antenna, LNA, downconverter).
  - Demodulation and error control.
  - Service selection and decryption.
  - Video, audio, and computer outputs.
  - Control processor and video decompressor.
  - Human interface.

* Service access control
  - Encryption of data stream.
  - User key distribution and control.
  - Security requirements of manufacturing and system database.

* Satellite Communication link
  - Modulation, Synchronization, and error control.
  - Satellite link budget.
  - Service multiplexing.

* Ground station systems architecture
  - Interface to Service Origination Network.
  - Physical plant requirements.
  - Uplink antenna and HPA.
  - Multiplexing and modulation equipment.
  - Service encryption and user key database.

* Service Origination Network
  - Originating terminal requirements for real-time operation.
  - Recorded media (e.g., video cassettes, audio cassettes, Digital Audio Tape).
  - Transmission media (e.g., telephone lines, leased digital links, satellite links).
  - Multi-node network architectures.

* Two-way services
  - Desirability of providing return transmission from users.
  - Feasibility of providing user terminals with return transmission capability.
  - Feasibility of providing a satellite link for return transmission from users.
  - Ground station requirements.
  - Communication link architecture (e.g., formats, modulation, protocols).
  - Traffic capacity and relative transmission cost.

* VCR simulation of services
  - Setup (or lease) facilities including cameras, monitors, VCRs, computer graphics, special effects and editing.
  - Generate simulation segments demonstrating each of the selected services. (No compression processing.)
  - Develop computer algorithm to statistically evaluate each segment and make estimations of the required (compressed) instantaneous transmission rate for various buffer sizes.
  - Determine time distribution statistics of each segment.
  - Prepare demonstration tape including each segment and edited to include an introduction, conclusion, and commentary on transmission requirements and relative costs.

* Plan for Phase 2
  - Identification of applicable technologies.
  - Plan for detailed receiver hardware design.
  - Plan for detailed ground system design.
  - Plan for detailed satellite communication design and Service Origination Network design.
  - Plan for ground system and receiver software development.
  - Plan for interfacing with manufacturers, potential service originators and users.
  - Plan for Phase 3 planning.
  - Management and Systems Engineering plan.
  - Cost estimates for Phase 2.